



ENERGY BALANCE IN THE MESOSPHERE AND THERMOSPHERE AS MEASURED BY SABER

Martin G. Mlynczak, NASA Langley Research Center
Linda Hunt, Science Systems and Applications, Inc
James M. Russell, Hampton University

•
The SABER Science Team

Acknowledgement

- Today we will look at data from the NASA TIMED satellite and the SABER instrument that was launched over 14 years ago on 7 December 2001.
- This talk is possible only because in the late 1990's, numerous engineers, project managers, resource analysts, and technicians did an excellent job of building and testing the TIMED instruments and satellite
- This talk is dedicated to them, for the outstanding job they did, which provides all of us the privilege of doing science with the data

Outline

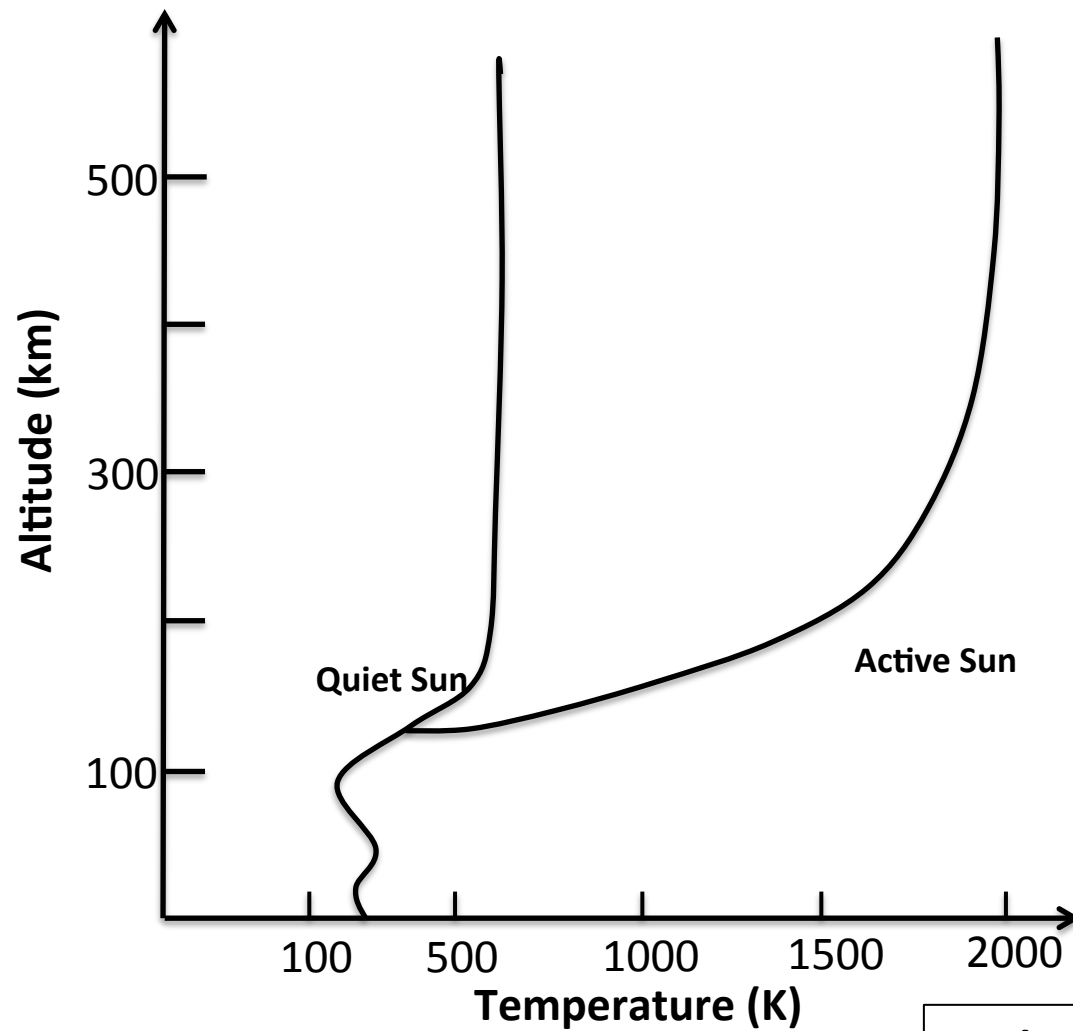
- **The Big Picture**
- **Overview of Thermosphere Energy Budget**
- **Radiative Cooling in the Thermosphere 2002 - present**
- **A View to the Past**
 - Are different solar cycles more similar than different?
- **Summary**

The Big Picture....

- Major objective is to understand the climate and energy balance of the thermosphere
- This is a very complex interaction of radiative transfer, chemical/gas kinetics, energy storage, energy conversion, and solar physics
- We have learned over the past 14 years of observations from the TIMED satellite that the energy budget varies on time scales from a *few days* to *decades*
- This presentation summarizes some of the major results to date

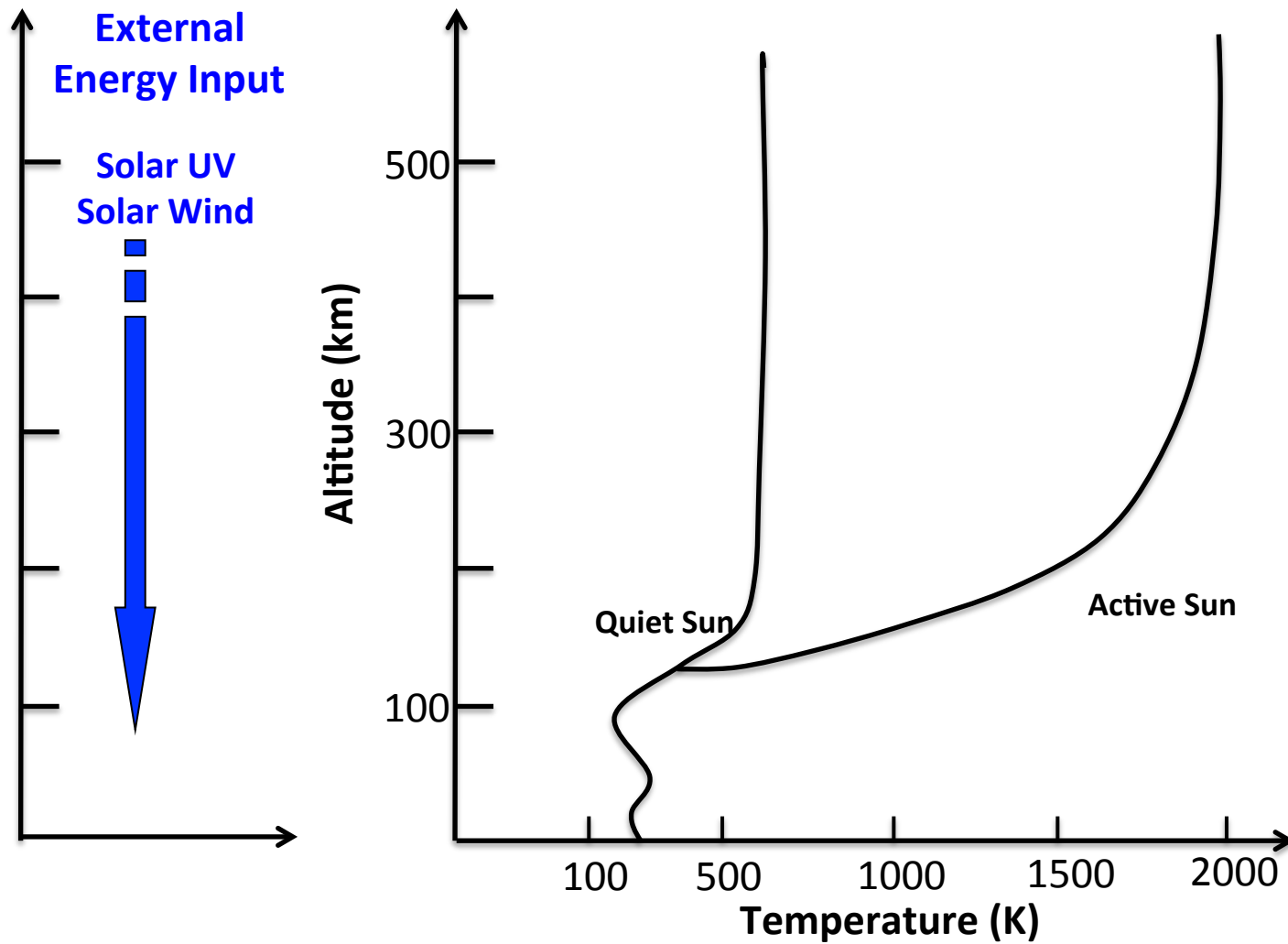
Overview of the Thermosphere Energy Budget

Thermosphere Energy Balance – Thermal Structure

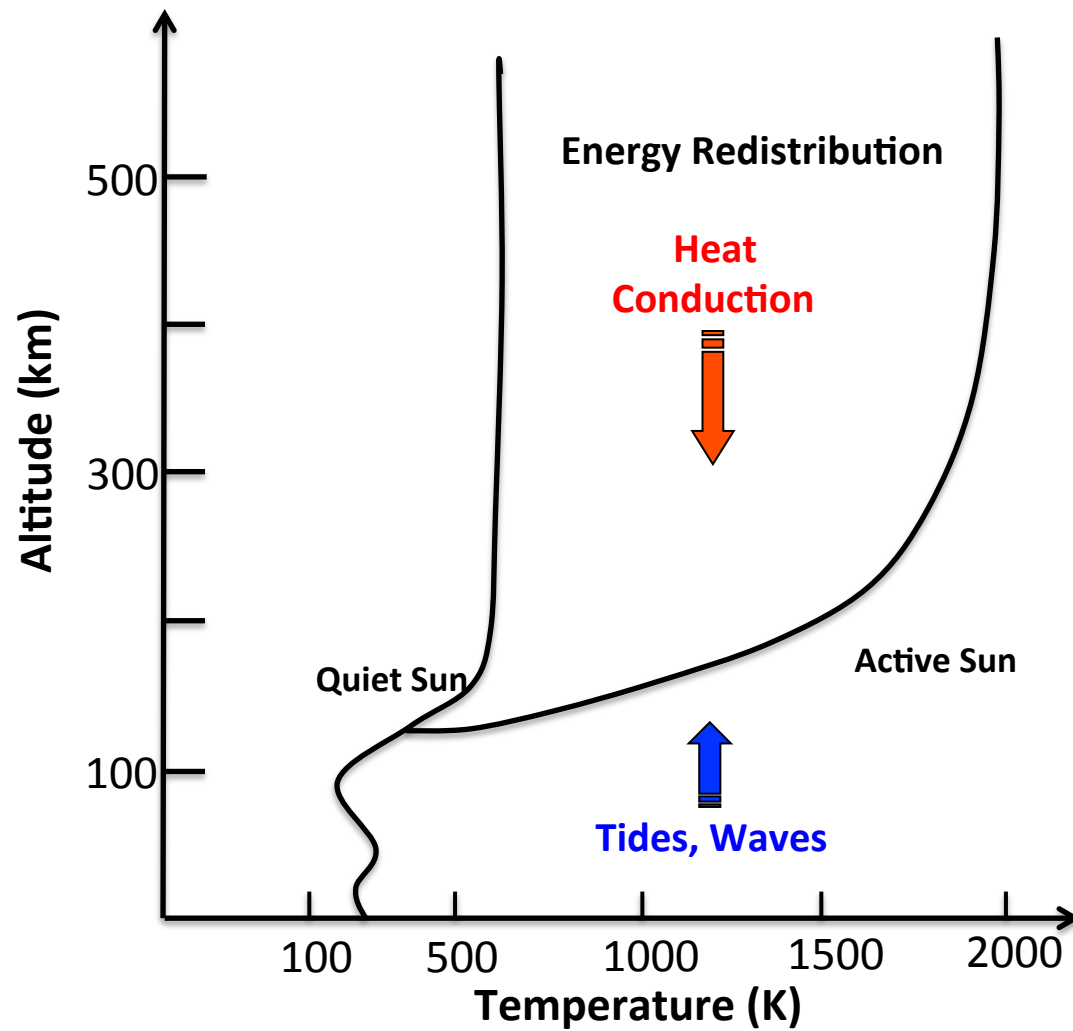


Banks and Kockarts, 1973

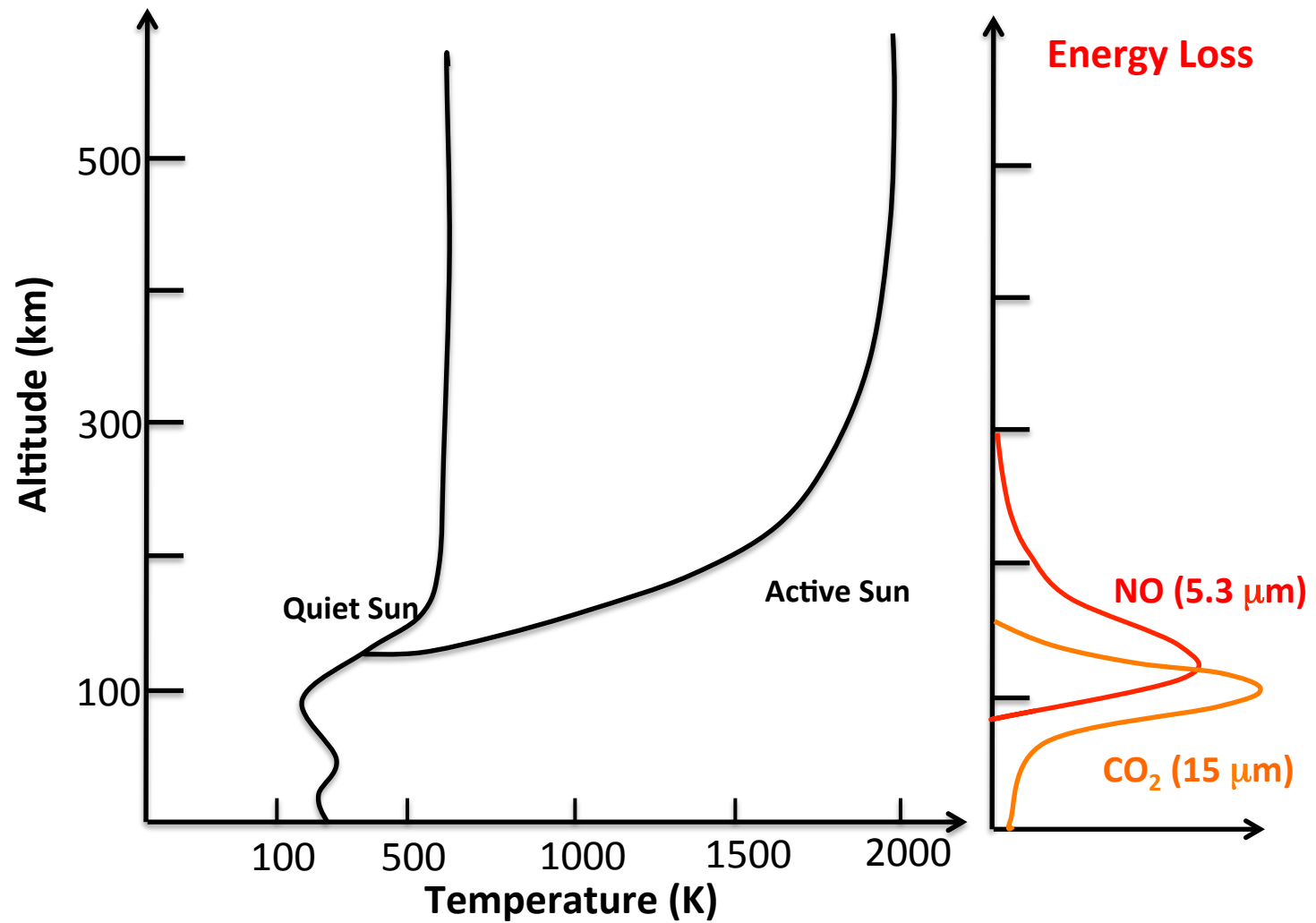
Thermosphere Energy Balance – Energy Inputs



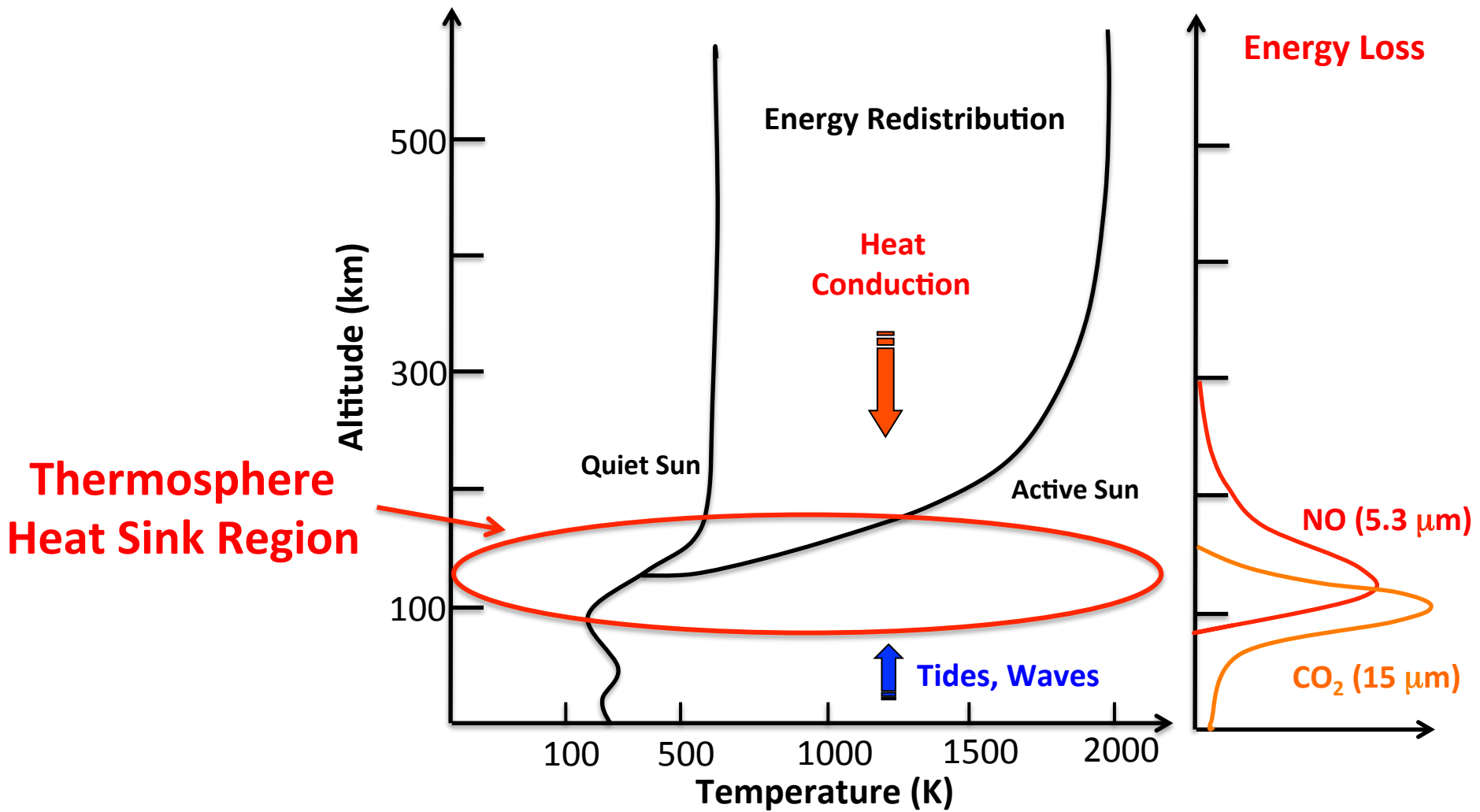
Thermosphere Energy Balance – Energy Redistribution



Thermosphere Energy Balance – Energy Outputs



Thermospheric Heat Sink



Radiative Cooling in the Thermosphere

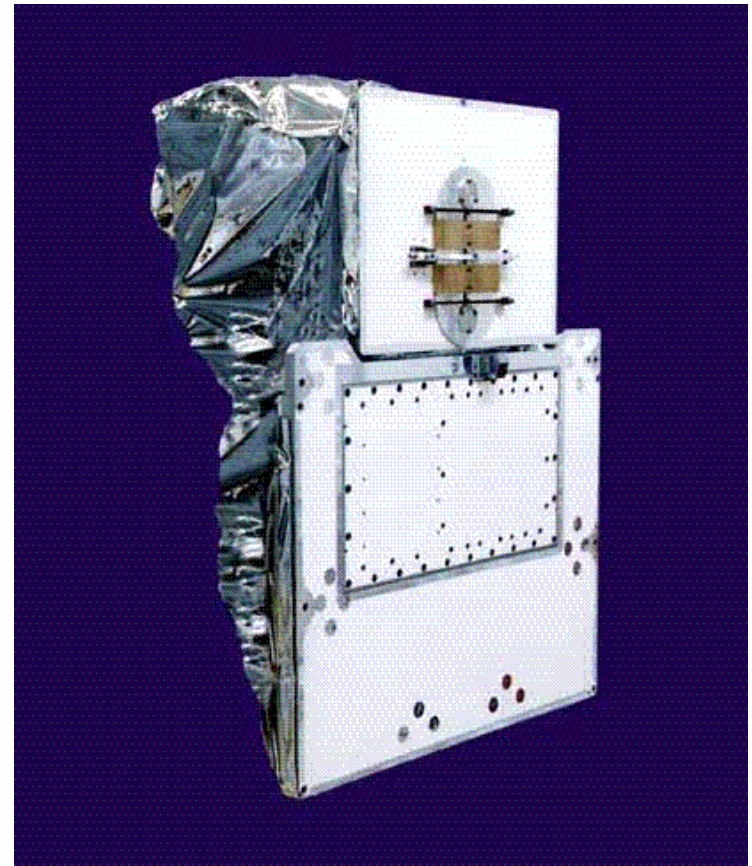
Radiative Cooling in the Thermosphere

- Radiative cooling is the action of infrared radiation to reduce the kinetic temperature of the neutral atmosphere
- It is accomplished almost entirely by two species:
 - Carbon Dioxide (CO₂, 15 μm)
 - Nitric Oxide (NO, 5.3 μm)
- Collisions between atomic oxygen (O) and CO₂ and NO initiate the cooling process:
 - NO ($v = 0$) + O → NO ($v = 1$) + O (Kinetic Energy Removal)
 - NO ($v = 1$) → NO ($v = 0$) + $h\nu$ (5.3 μm) (Kinetic Energy Loss)
 - NO ($v = 1$) + O → NO ($v = 0$) + O (Kinetic Energy Returned)
- Collisional process are highly temperature dependent

Sounding of the Atmosphere using Broadband Emission Radiometry -- SABER --

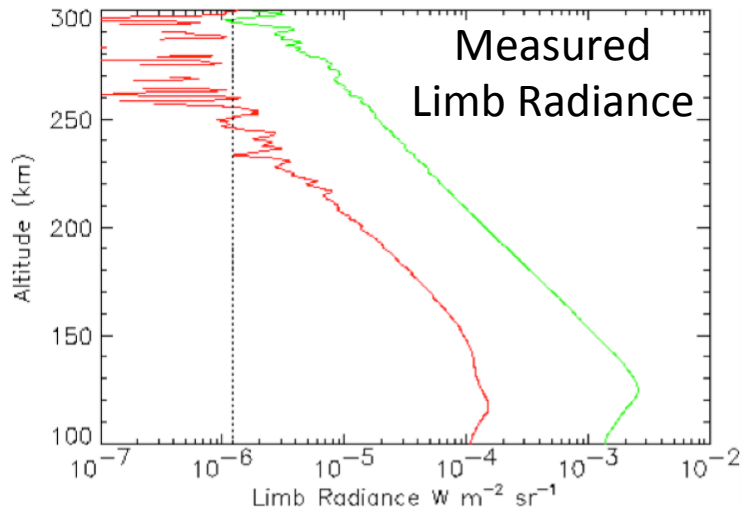
SABER Experiment

- Limb viewing, 400 km to Earth surface
- Ten channels 1.27 to 16 μm
- Over 30 routine data products including energetics parameters
- 8.3 million radiance profiles – per channel!
- Cryo-cooler operating excellently at 77 K
- Noise levels at or better than measured on ground
- Now in 15th year of on-orbit operation
- **Over 1200 refereed journal articles!**

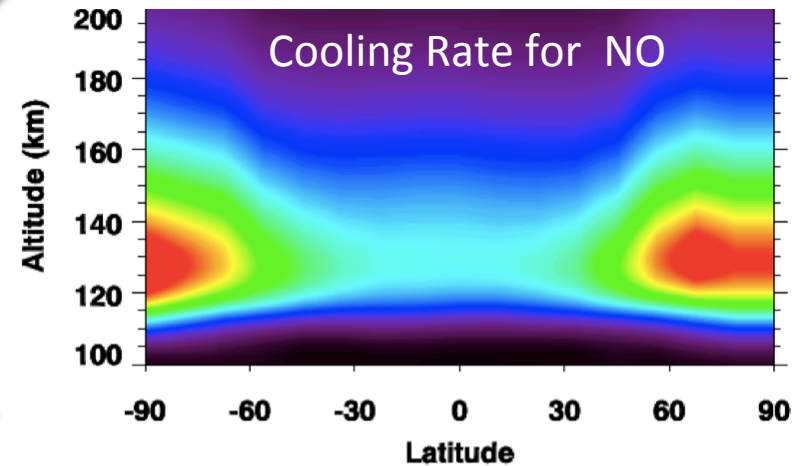


75 kg, 77 watts, 77 x 104 x 63 cm, 4 kbs

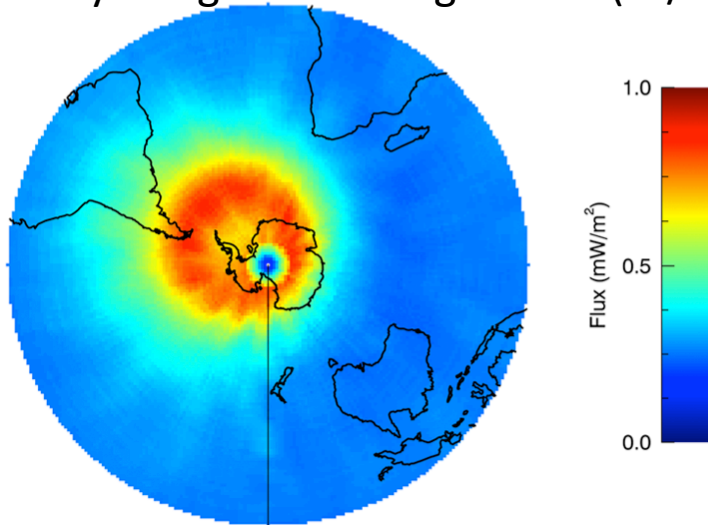
NO and CO₂ Cooling Parameter Derivations by SABER



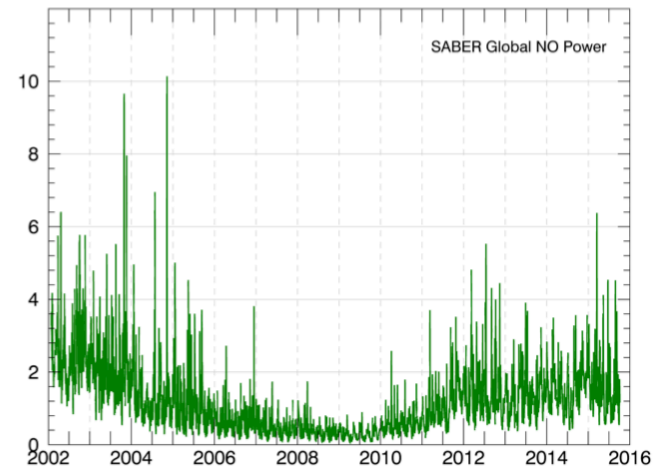
Abel Inversion to Cooling Rate (W/m^3)



Vertically Integrate Cooling to Flux (W/m^2)

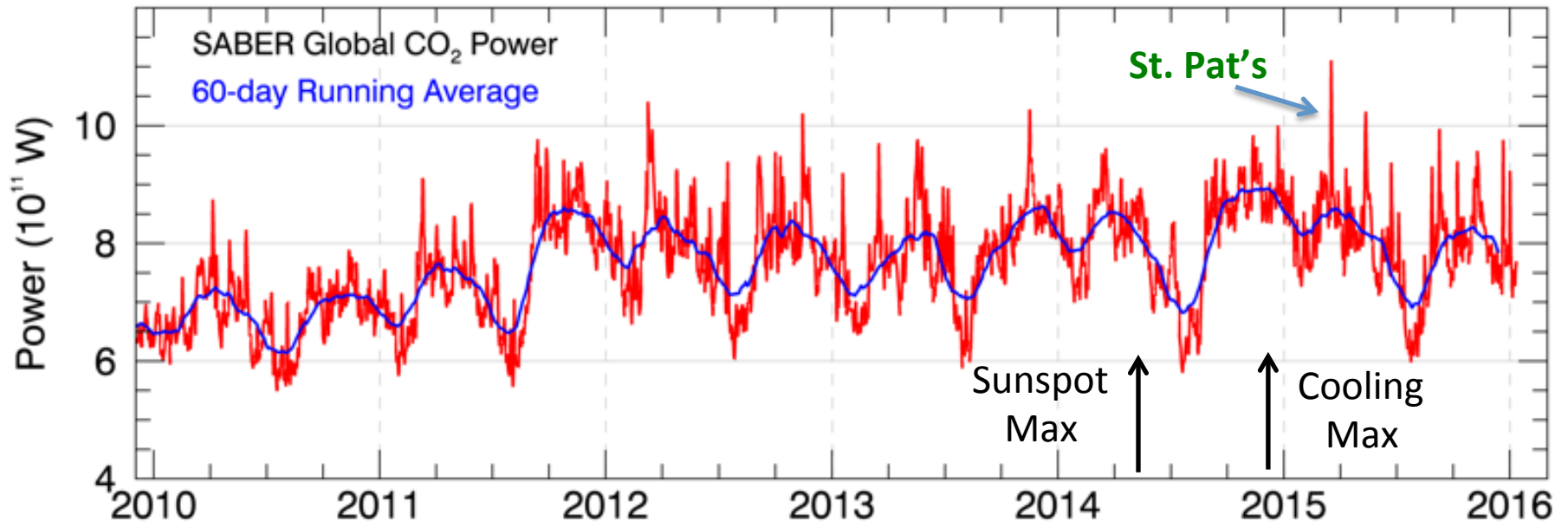


Area integrate
to get global
power (W)



SABER Global Power from CO₂ in SC 24

Jan 2010 – Dec 2015; 100 – 140 km



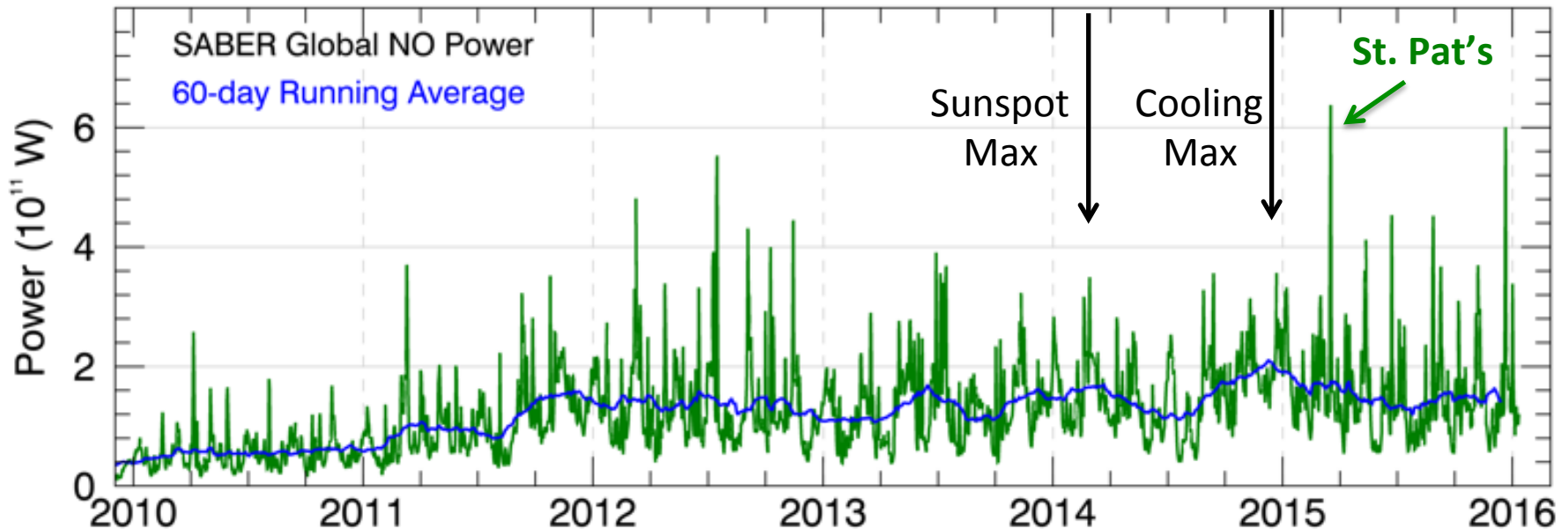
Sunspot and cooling maxima are not coincident

Strong semi-annual oscillation evident

Geomagnetic activity always evident in radiative cooling

SABER Global Power from NO in SC 24

Jan 2010 – Dec 2015; 100 – 250 km

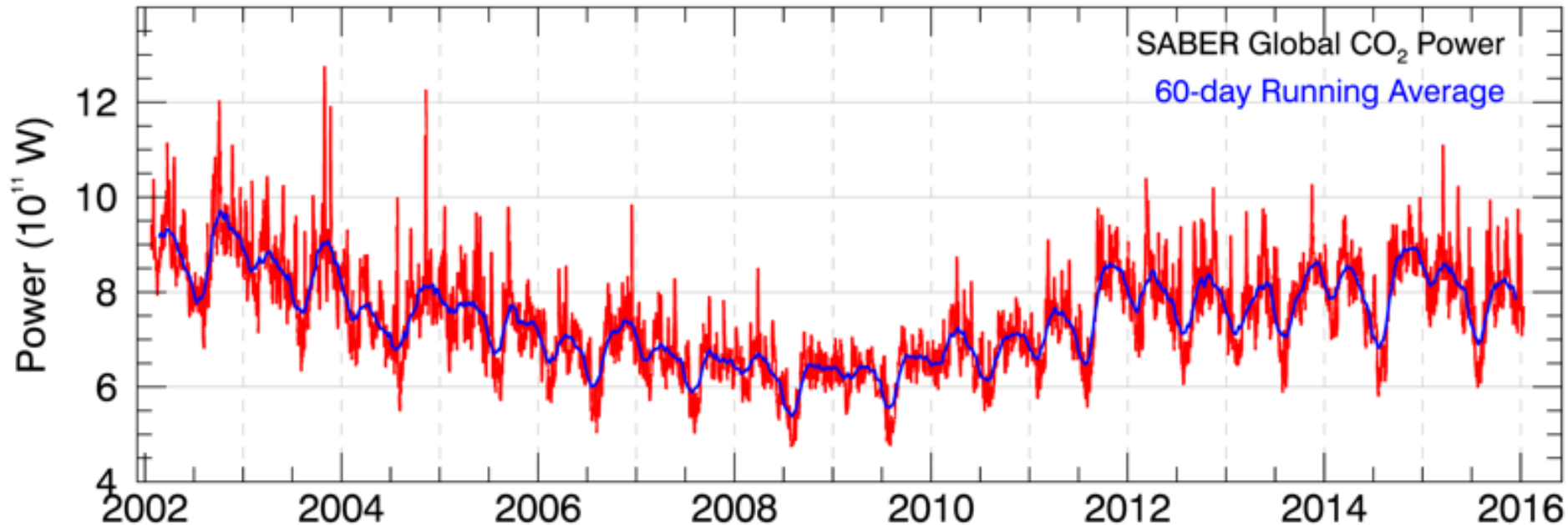


Sunspot and cooling maxima not coincident
Each “spike” is the response to a geomagnetic event
St. Patrick’s Day Storm is largest event since 2010

SABER Global Power from CO₂

Jan 2002 – Dec 2015; 100 – 140 km

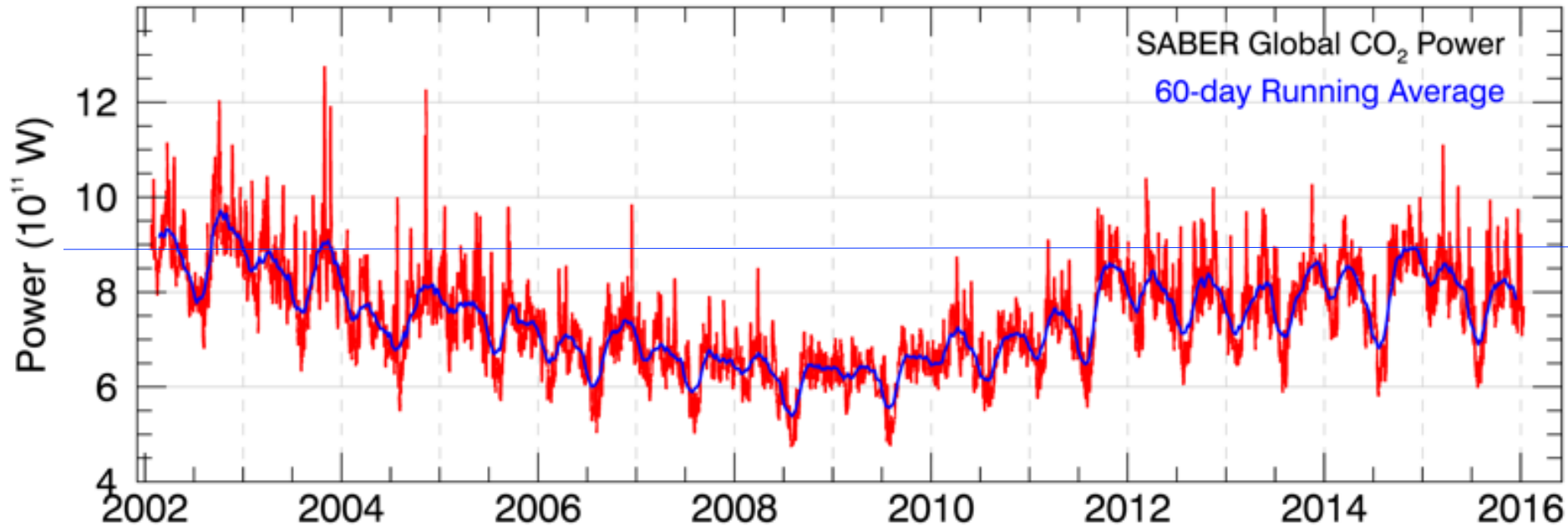
Over 5200 days of data!



Strong semi-annual cycle evident in global cooling
Evidence of response to geomagnetic activity in each “spike”

SABER Global Power from CO₂ Jan 2002 – Dec 2015; 100 – 140 km

Over 5200 days of data!

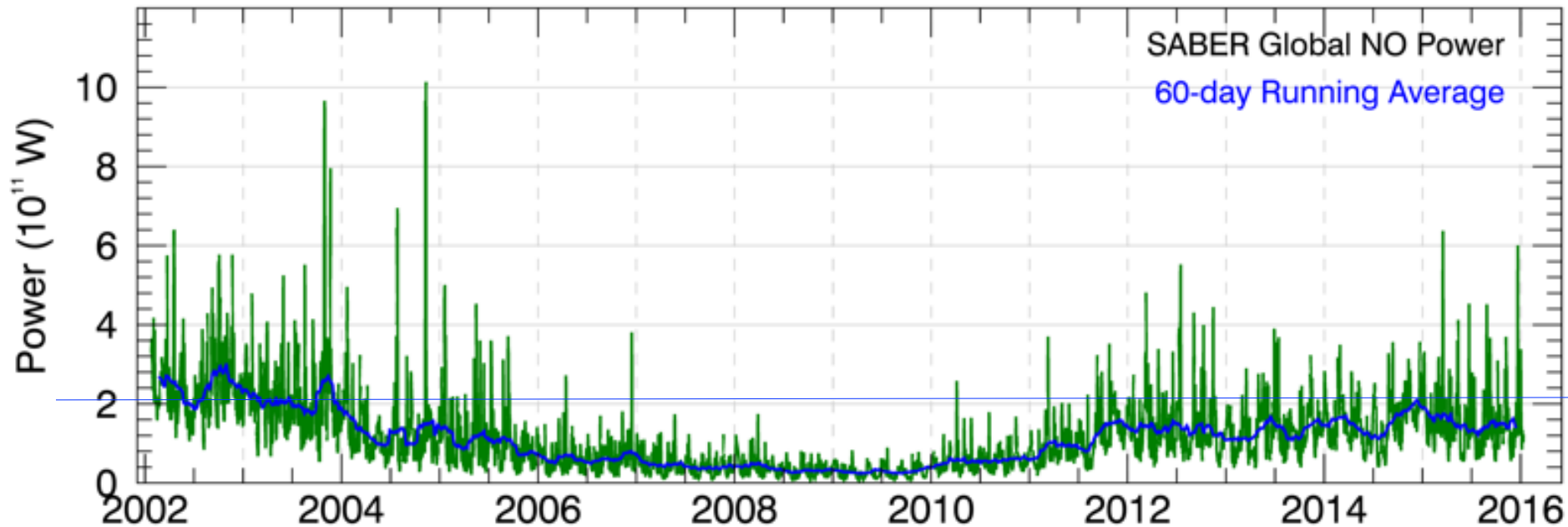


SC 24 solar max (12/2014) as warm as 12/2003 – 11 years
SC 24 peak clearly weaker than SC 23

But, just how different in total energy are they?

SABER Global Power From NO

Jan 2002 – Dec 2015: 100 – 250 km

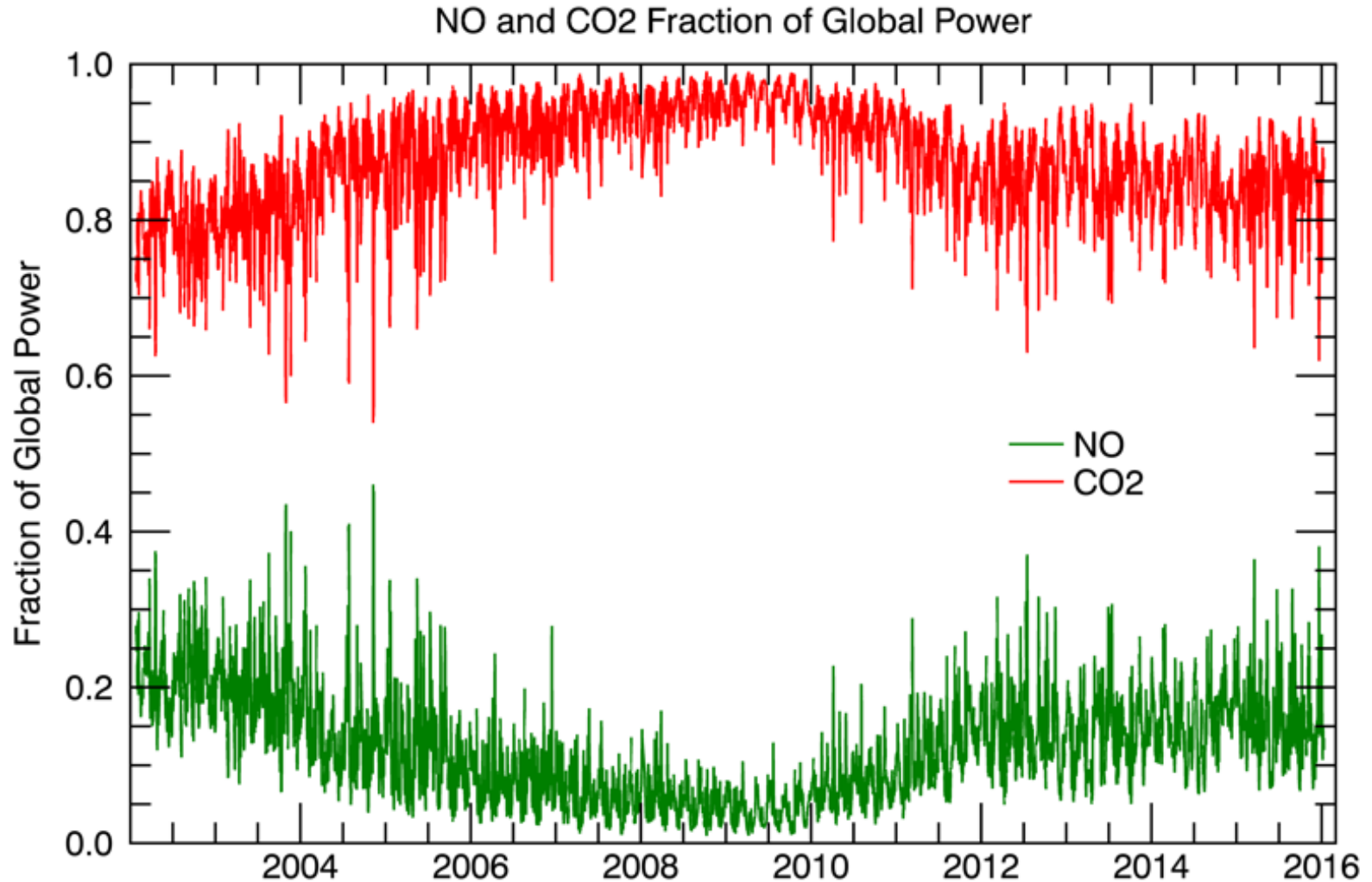


NO Cooling at Peak of SC 24 (12/2014) was highest level since 12/2003

From the perspective of integrated energy, just how different is one solar cycle from another?

Fraction of Thermosphere Global Infrared Power

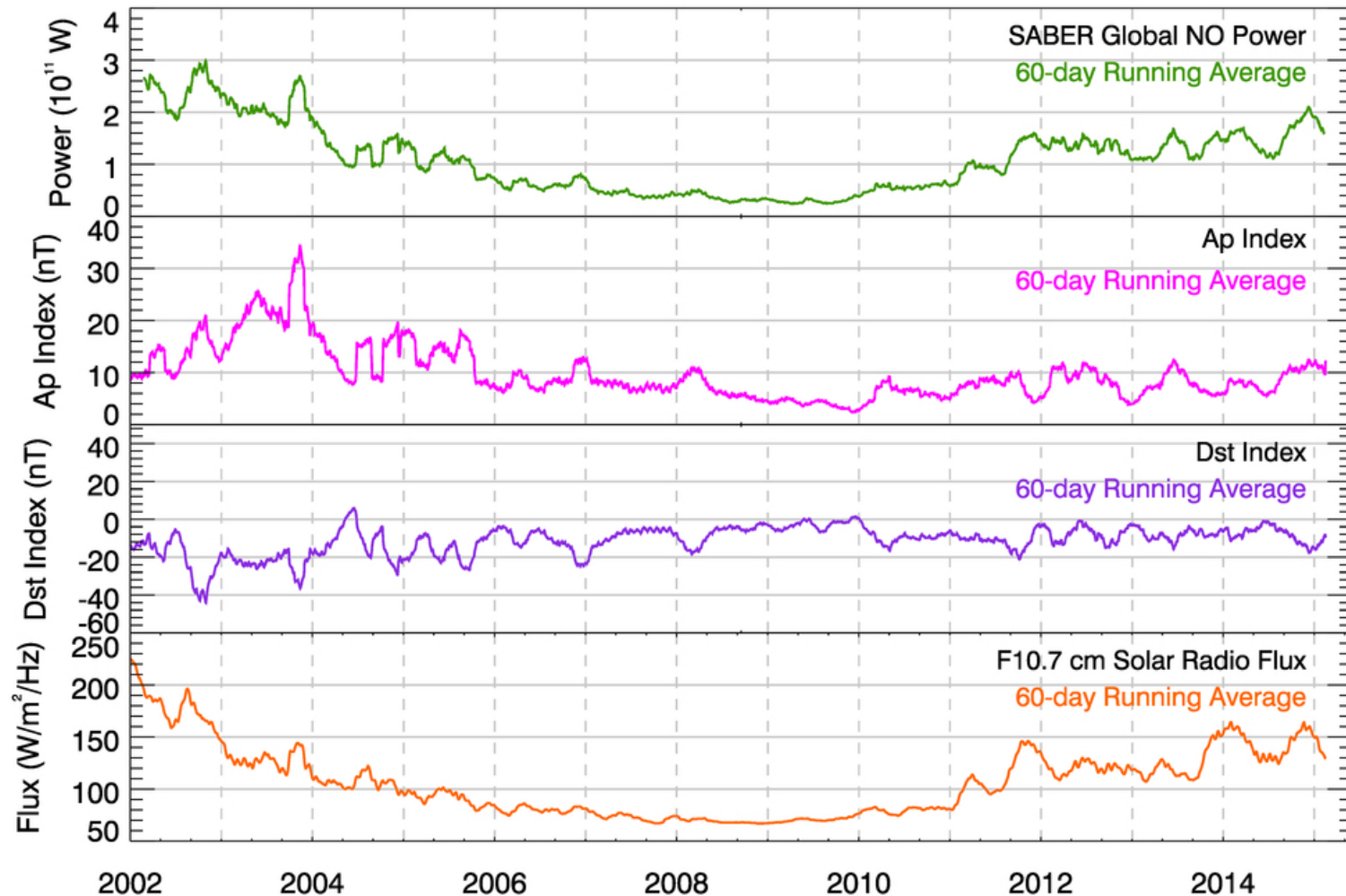
- CO₂ and NO -



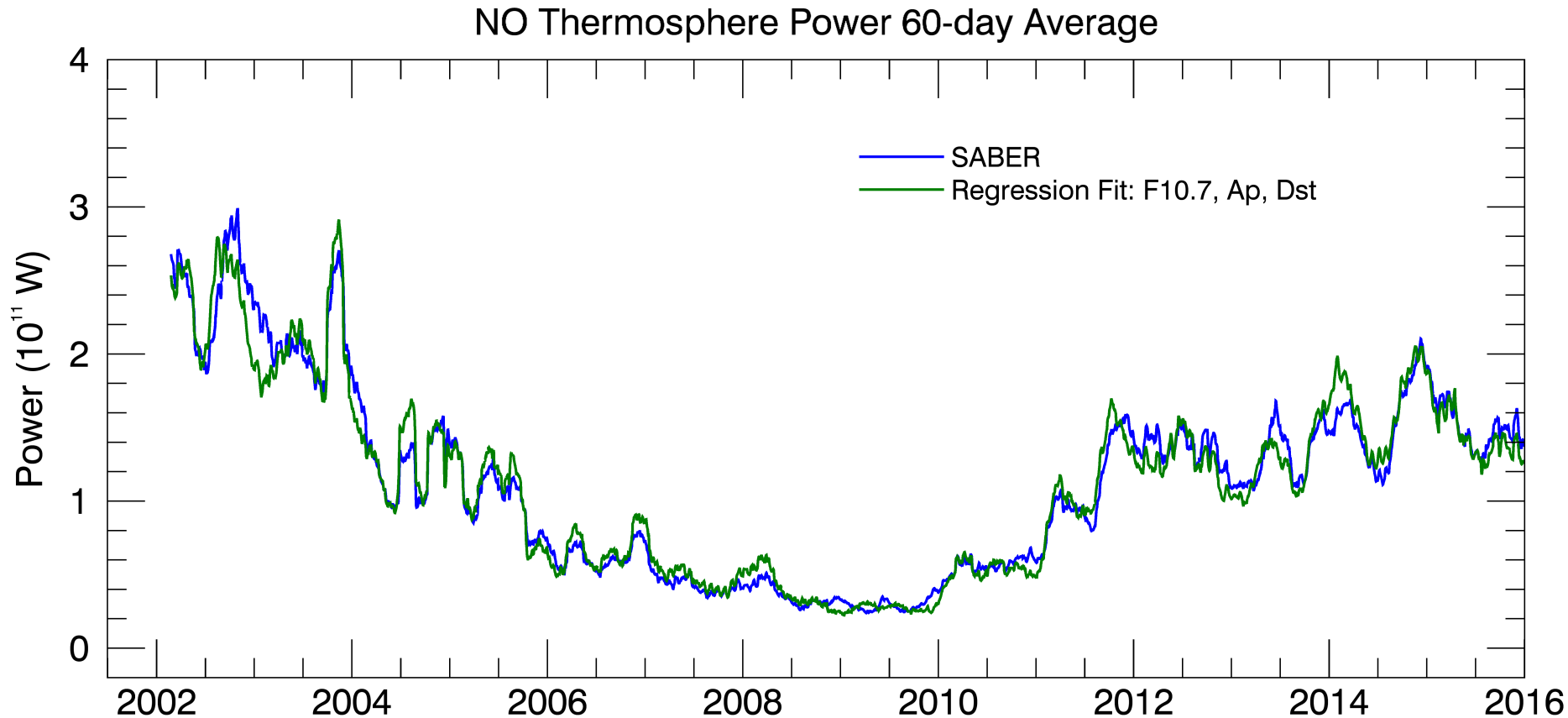
A View to the Past

60-day Running Means – Nitric Oxide Power

Strong Visual Correlation in NO, Ap, Dst, F10.7



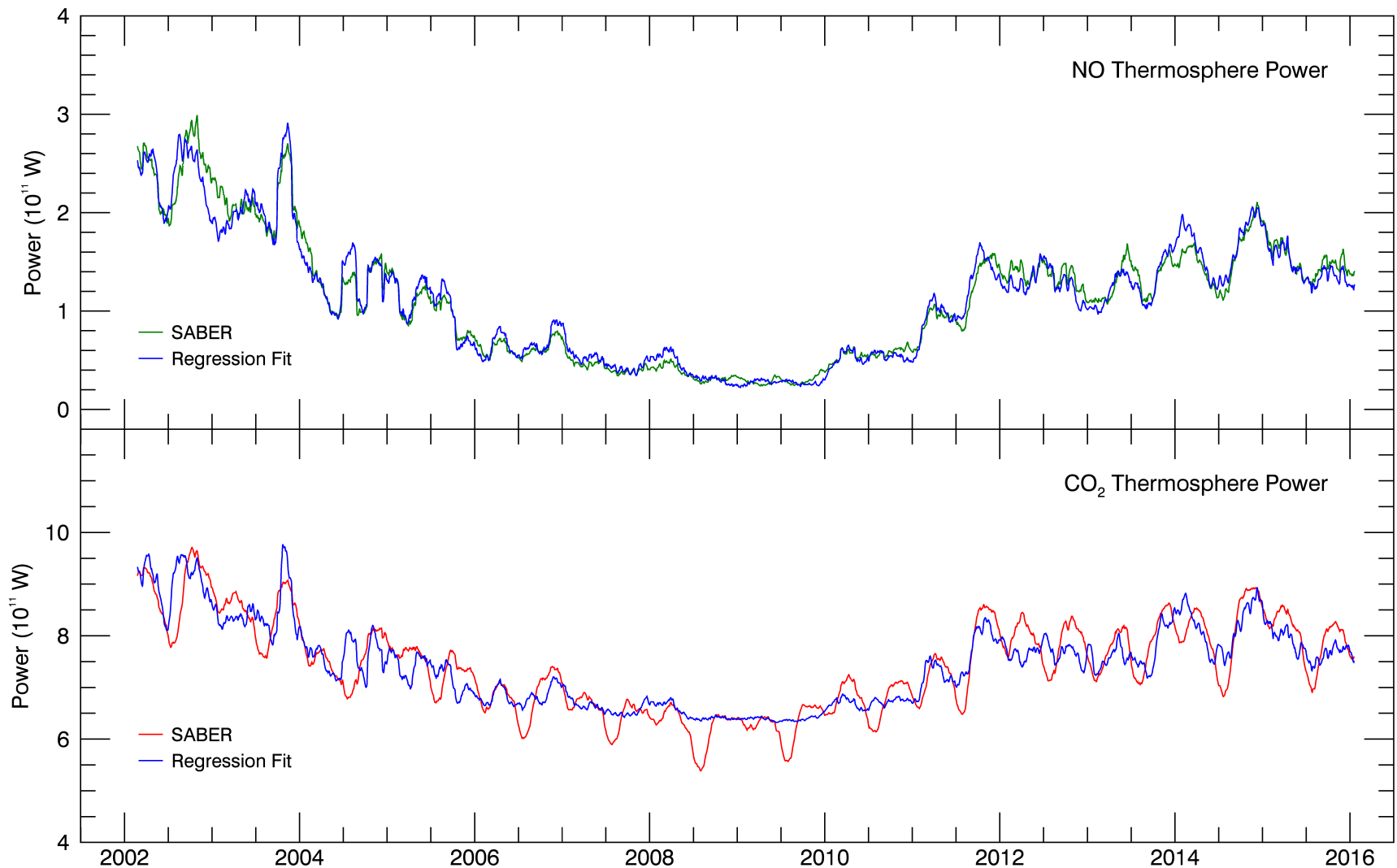
Multiple Linear Regression Fit NO Power as Function of F10.7, Ap, Dst



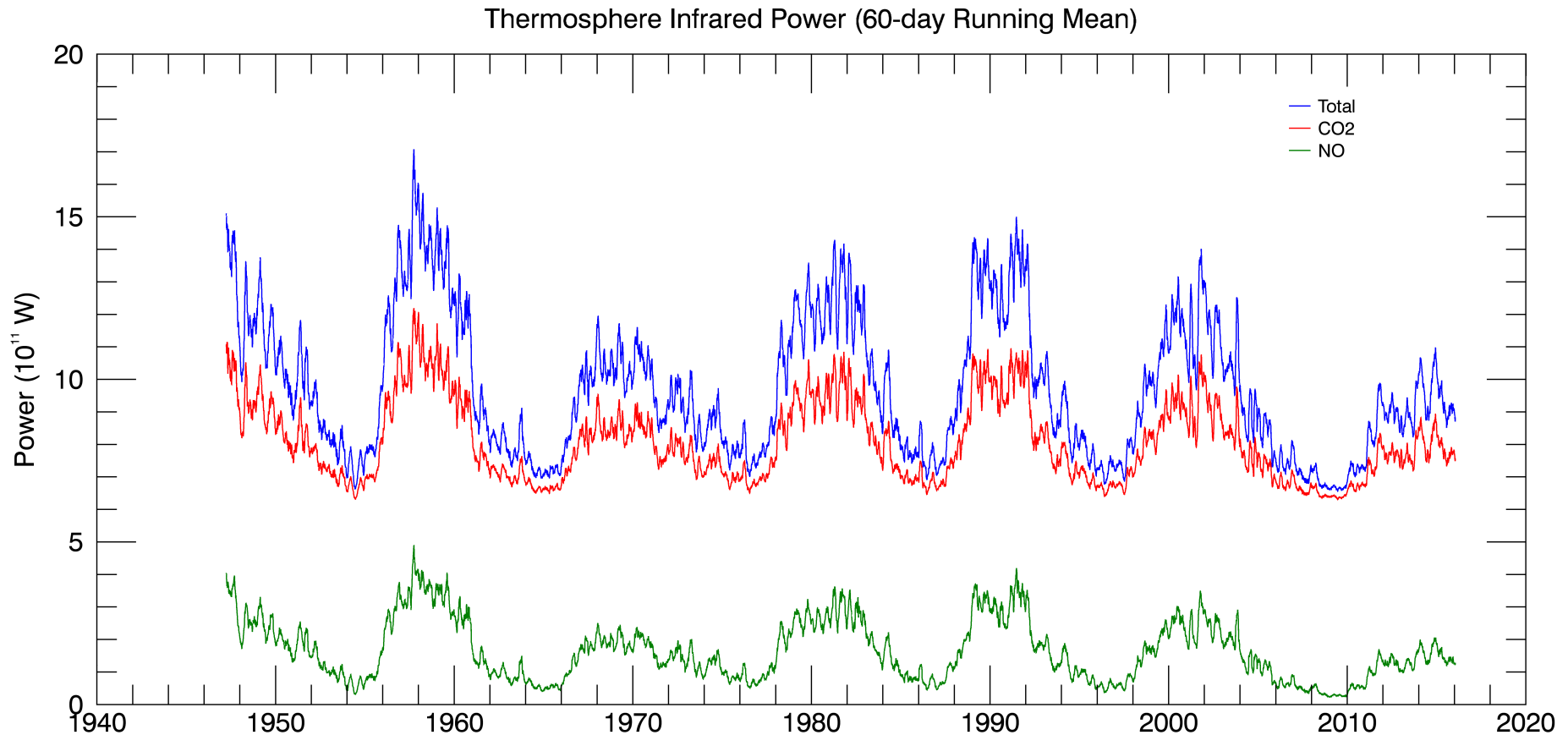
Reconstruct cooling time series back to 1947 using extant F10.7, Ap, Dst

Multiple Linear Regression Fit

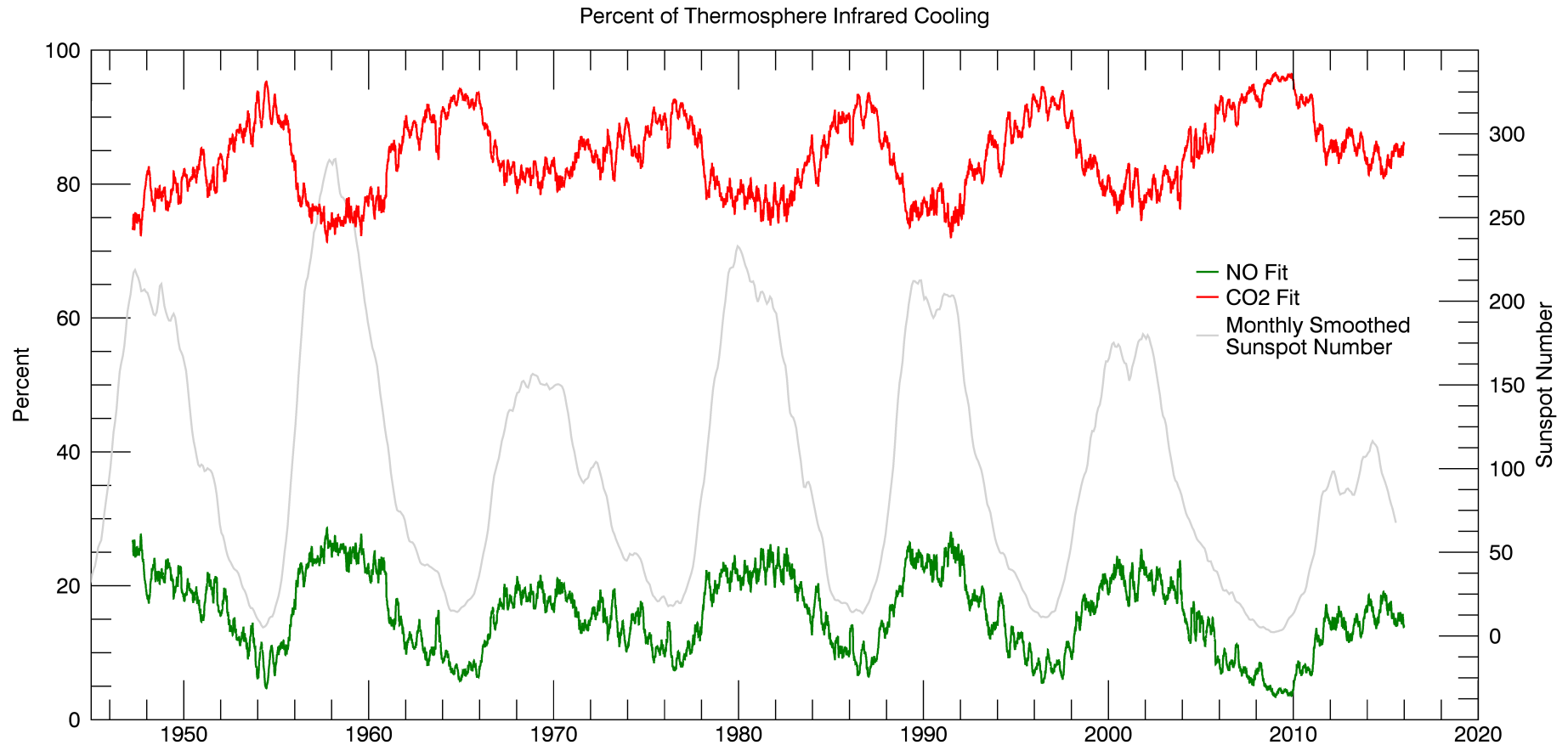
Power as Function of F10.7, Ap, Dst



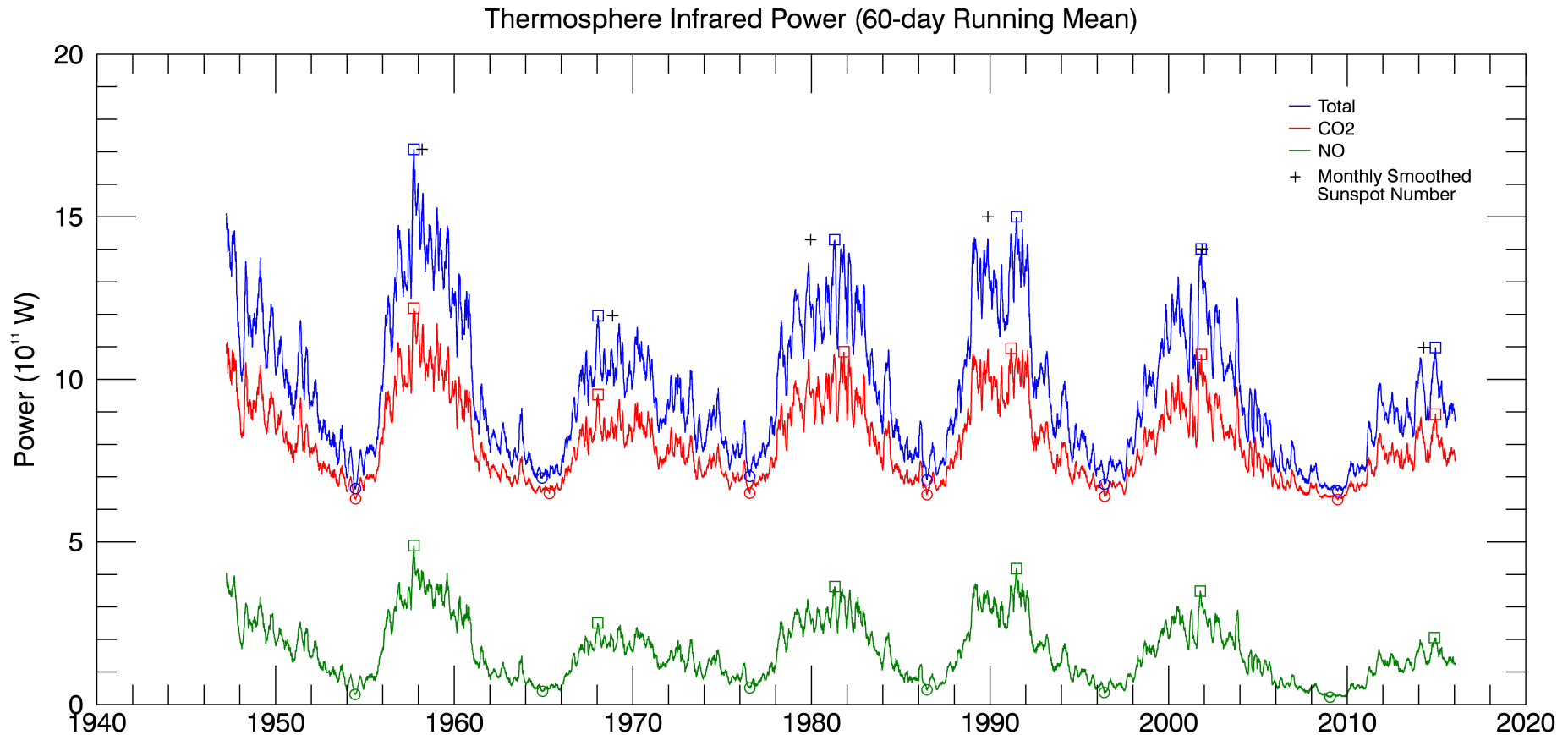
Thermosphere Infrared Power Function of F10.7, Ap, Dst



Percent of Thermosphere Infrared Cooling CO₂ and NO

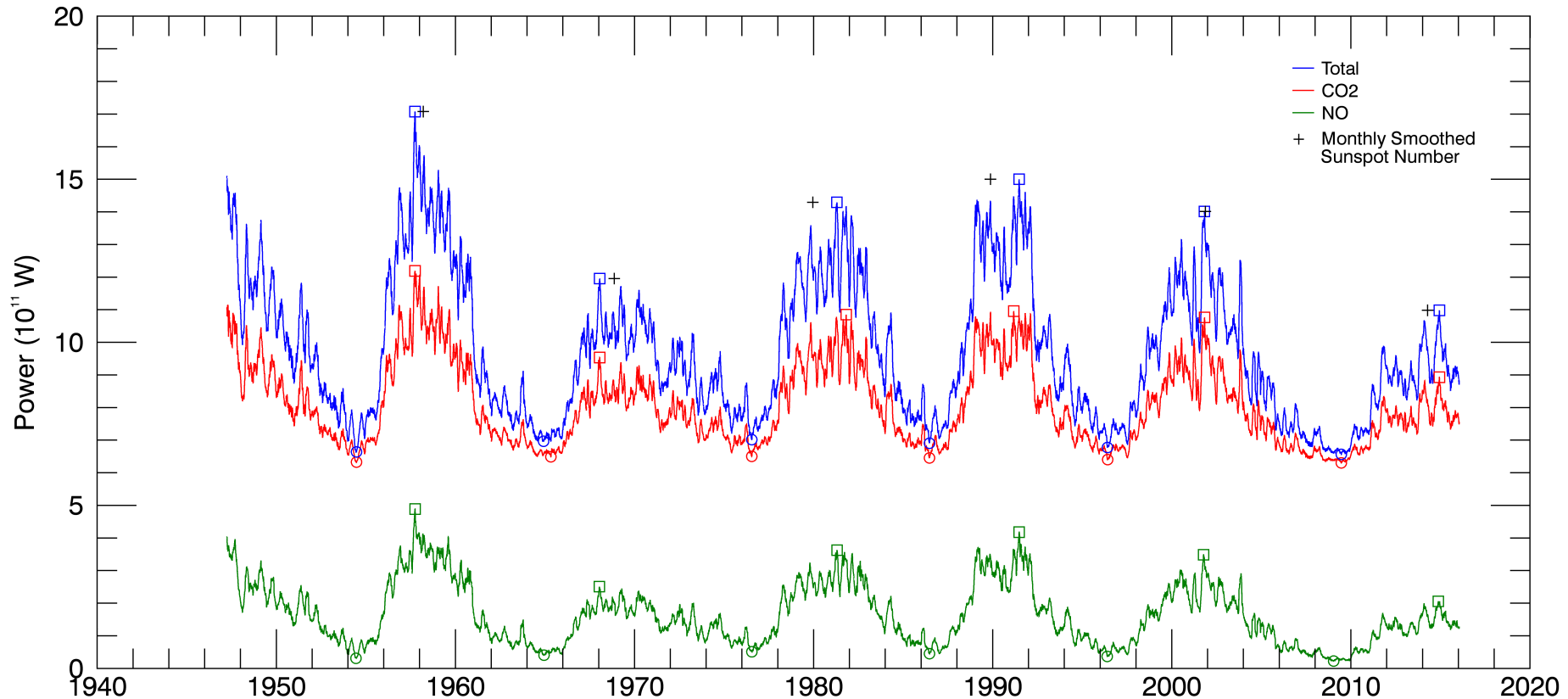


Multiple Linear Regression Fit Power as Function of F10.7, Ap, Dst



Multiple Linear Regression Fit Power as Function of F10.7, Ap, Dst

Thermosphere Infrared Power (60-day Running Mean)



Solar Cycle	NO Power	CO2 Power	Total Power
19	7.49E+14	3.26E+15	3.90E+15
20	5.87E+14	3.18E+15	3.87E+15
21	6.86E+14	3.03E+15	3.72E+15
22	6.69E+14	3.02E+15	3.69E+15
23	6.51E+14	3.69E+15	4.34E+15

Summary

- SABER data illustrate a very complex and interesting thermosphere that responds to solar variability on timescales from days to decades
- Past 5 solar cycles vary show IR emission from atmosphere varies by at most 25% -
 - *Are solar cycles more similar than different?*
- Solar maximum, from the atmosphere's perspective, does not have a consistent relationship to the sunspot number
 - *Are new metrics for solar max/min for atmosphere response needed?*